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Shallot Yield, Quality and Shelf-life as Affected by Nitrogen Fertilizer

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Shallot (*Allium cepa* var *ascalonicum* Baker) can be a substitute where bulb onion (*A. cepa* L. var *cepa*) does not do well. However, production and productivity of shallot can be limited due to poor soil fertility; lack of improved production techniques; unimproved varieties, and high post-harvest losses. Farmers in northeastern Ethiopia rarely apply fertilizers to shallot. A field study was undertaken in that region in 2007/2008 to determine effects of nitrogen fertilizer on yield and shelf-life of shallot. Treatments were 0, 50, 100, and 150 kg·ha^{-1} N and cvs. 'Huruta,' 'Negelle,' 'Dz-sht-68,' and a local landrace. Application of 150 kg·ha^{-1} of N increased marketable and total bulb yields by 26% over the control. The highest and the lowest marketable bulb yields were for 'Dz-sht-68' and the local landrace, respectively. In storage nitrogen fertilization increased bulb weight loss in all cultivars, with weight loss being highest for the local landrace. Nitrogen fertilization at 150 kg·ha^{-1} N increased bulb rotting up to 79% over the control. Shallot shelf-life was of short duration. Application of 100 kg·ha^{-1} N was optimal for shallot bulb production without affecting bulb quality.

Keywords Bulb rot, Cultivar, Ethiopia, pungency, TSS.

In areas where bulb onion (*Allium cepa* L. var *cepa*) production is difficult, shallot (*A. cepa* var *ascalonicum* Baker) can be cultivated. Shallot is produced in mid- and high-altitude areas of Ethiopia. However, productivity of shallot is generally low (~10-14 Mt·ha^{-1}) (CAC, 2002) compared with experimental plot yields of >20 Mt·ha^{-1}. This gap is likely due to moisture stress, low soil fertility, disease and insect pests, and unimproved cultivars. Nitrogen deficiency limits crop productivity. Under sub-optimal N, shallots can be stunted, with bulb size and marketable yields reduced (Kebede, 2003a). Too much nitrogen can result in excessive vegetative growth, delayed maturity, increased

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susceptibility to diseases, reduced dry matter content and storability, and reduced yield and quality of marketable bulbs (Kebede, 2003b).

Long shelf-life of shallot bulbs, with little loss of weight, and other quality parameters, are important for obtaining high prices. Storage of shallot bulbs after harvesting poses a problem for growers in tropical regions due to post-harvest loss owing to reduced bulb weight, bulb rotting, bulb sprouting and bulb rooting (Sebsebe and Workneh, 2010). A complex interaction of pre- and post-harvest factors, which include mineral nutrition; cultivar; bulb maturity; and conditions during maturation and harvesting and curing affect bulb shelf-life (Kale, 2010). Sebsebe and Workneh (2010) reported increased bulb rotting and sprouting, loss in bulb diameter, bulb weight loss and unmarketability due to increased N application. Tekalign et al. (2012) indicated that increased rates of N and P fertilizers increase cumulative weight loss, bulb sprouting, and rotting in onion. Kale (2010) reported reduced onion shelf-life and quality due to high N fertilizer.

High storage loss could compel shallot producers to sell their product immediately after harvest when the price is low. Absence of cultivars with good keeping quality and lack of storage facilities aggravate the problem. Although research results are available on effects of nitrogen fertilizer on productivity and shelf-life of allium species, response to nitrogen fertilizer generally varies from place to place as it is based on soil fertility status, environmental condition and the cropping system.

Farmers in northeastern Ethiopia rarely apply fertilizers to shallot. It is necessary to identify nitrogen fertilizer levels for each area and production system to improve productivity with little impact on shelf-life. It is also necessary to identify high yielding cultivars with better storability to reduce post-harvest losses. The study was conducted to determine nitrogen fertilizer rates and cultivars for higher yield, quality and lower post-harvest loss of shallot.

MATERIALS AND METHODS

Experimental Site

The field experiment was conducted at the Haik research sub-center of Sirinka Agricultural Research Center, at 11° 21' N latitude and 39° 38' E longitude, altitude of 1680 m above sea level. Mean annual rainfall, and minimum and maximum temperatures, were 1205 mm, 11.2 °C, and 25.6 °C, respectively. The soil was a silty sand, pH 7.12, low in total nitrogen (0.165%; Bremner and Mulvancy, 1982), deficient in available phosphorus (8.73 mg·kg^{-1}; Olsen et al., 1954), and very low in organic matter contents (1.745%; Walkley and Black, 1934). The soil had a high cation exchange capacity (32.04 meq/100 g) and high exchangeable bases (28.22 meq/100 g Ca^{2+}, 2.25 meq/100 g K^+ and 4.17 meq/100 g Na^+; Black, 1965).

The storage experiment was conducted under temporary shelters at the Sirinka Agricultural Research Center, northeastern Ethiopia located at 11° 83' N latitude and 39° 68' E longitude at an altitude of 1,850 m above sea level. Mean annual relative humidity was 66.5% with mean annual maximum and minimum temperatures of 26 °C and 13 °C, respectively.

Experimental Design and Procedures

Combinations of nitrogen fertilizer (0, 50, 100, and 150 $kg{\cdot}ha^{-1}$ of N) and shallot cvs. ('Huruta,' 'Negelle,' 'DZ-sht-68,' and a local landrace) were arranged in a factorial experiment in a randomized complete block design and replicated 3 times. Plot size was 9.6 m^2 (3 m × 3.2 m). 'Huruta' and 'Negelle' are commercial varieties; 'DZ-sht-68' is a promising cultivar for release. The local landrace is yellow-skinned.

The soil was plowed to a depth of 35 cm, disked, leveled and made into raised beds. Bulbs were planted at 0.2 m between plants in rows spaced 0.4 m and with 2 m and 1.5 m spacing between blocks and between plots, respectively. Half of the nitrogen fertilizer, as urea, was applied at 50% bulb sprout and half 1 mo later. Phosphorous (92 $kg{\cdot}ha^{-1}$ P_2O_5) as triple super-phosphate, was applied in rows to all plots at planting on 20 December 2007. Generally, Ethiopian soils are high in K and K fertilizers are not used on any crops. Plots were irrigated at 5 cm water depth at 5-day intervals until maturity. No fungicides or insecticides were applied as there was no disease and insect incidence. Plots were kept weed free throughout the season with hand weeding. Harvest was on 18 April 2008. After harvest, bulbs were cured by spreading on the ground in thin windrows for 7 days before topping and data collection.

Data on growth and yield related traits were recorded from 10 randomly selected plants from the central 6 rows of each plot. Size of mature bulbs was measured at the widest point and bulb weight recorded as average weight of mature bulb splits. Total biomass yield per plant was recorded as sum of bulb yield, shoot and roots, at maturity. Dry matter was determined on 250 g samples taken from 10 bulbs per plot, where the sample was oven dried at 70 °C until constant weight was achieved. Marketable bulbs were graded by diameter into small (20–35 mm), medium (> 35–50 mm), and large (> 50 mm) as described by Kebede et al. (2002). Damaged and bulbs < 20 mm diameter were graded as unmarketable. Data on total soluble solids (TSS) was determined using procedures of Waskar et al. (1999). Content of pyruvic acid in the bulb tissue was used as a measure of pungency following procedures of Ketter and Randle (1998).

For the storage experiment marketable bulbs, harvested from each treatment in the field experiment, were cured and used. The storage experiment was conducted between 25 April and 24 July 2008. Five kilograms of marketable bulbs were stored from each treatment on shelves in grass-thatched roofed buildings, arranged in a randomized complete block design with three replications, at ambient atmospheric conditions. Fresh weight of bulbs was recorded at the start of the study. Daily storage temperature and relative humidity were recorded every 3 hrs using a hygrothermograph.

Percent bulb weight loss was determined using methods described by Waskar et al. (1999). Weight loss was recorded from 30 randomly selected bulbs per treatment. Bulbs were weighed at the beginning and middle of each month. Percent bulbs sprouted and rooted were calculated. Sprouted bulbs were discarded, rooted bulbs were labeled after each count to avoid double counting. Bulbs sprouted, but rotted, were classified as sprouted. Bulbs with roots, but rotted, were classified as rooted. Rotted bulbs were discarded after each count to avoid double counting and to reduce spread of rot organisms.

Data were subjected to analysis of variance (GLM procedure) in SAS (ver. 8.2, SAS, Inc., Cary, NC). If interactions were significant they were used to explain results. If interactions were not significant main effect means were separated using Tukey's test.

RESULTS AND DISCUSSION

Average daily maximum and minimum temperatures and relative humidity during the experimental period were 31.6 °C, 15.8 °C, and 46%, respectively, and are representative of the long-term record.

Bulb Yields

Marketable and total bulb yields were affected by nitrogen rate and cultivar, but not by the interaction (Table 1). Marketable and total bulb yields increased as N level increased; the highest marketable and total bulb yields were due to application of 100 and 150 $kg{\cdot}ha^{-1}$ N (Figure 1). Application of 100 $kg{\cdot}ha^{-1}$ N appears to be the agronomic optimum in terms of marketable and total bulb yields in shallot on a silty sand soil.

Table 1: Analysis of variance for effects of nitrogen fertilizer and cultivar on marketable and total bulb yield, number of bulb splits per plant, bulb diameter, bulb dry matter and TSS of shallot (mean square values).

Source of variation	df	Marketable yield	Total yield	Bulb split	Bulb diameter	Bulb dry matter	TSS[a]
N rate (N)	3	68.173**	75.266**	24.29***	65.64**	1.45*ns*	2.05*
Cultivar (C)	3	820.128***	750.829***	14.77***	396.38***	22.71***	5.46***
N × C	9	3.042ns	3.418ns	3.11***	27.72*	1.58ns	1.51ns
Error	30	11.839	11.605	0.47	9.23	1.05	0.70

ns = Non-significant. **Significant at $p \leq 0.01$. ***Significant at $p \leq 0.001$. [a]TSS = Total soluble solids.

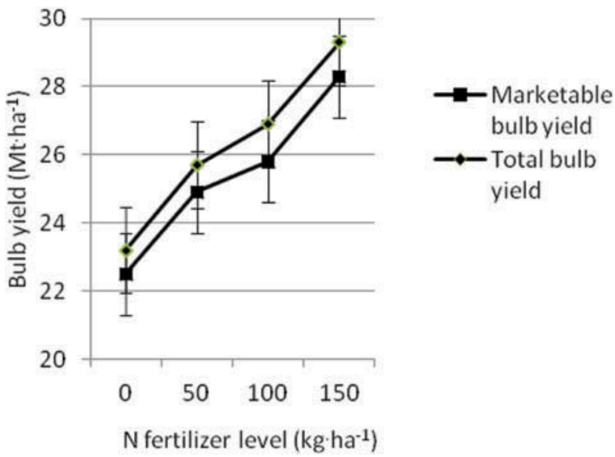

Figure 1: Effect of N fertilizer on marketable and total bulb yields of shallot in 2008.

Sebsebe and Workneh (2010) reported that fresh bulb yields in shallot were higher with application of 100 kg·ha^{-1} of N. Kebede (2003b) reported yield increase in shallot with application of N fertilizer in the range of 75–150 kg·ha^{-1} of N. Jilani et al. (2004) reported yield increase in bulb onions with application of nitrogen in the ranges of 40–200 kg·ha^{-1}. Abdissa et al. (2011) reported that application of N at 69 kg·ha^{-1} increased total and marketable bulb yield of bulb onion. Amounts of nitrogen used in this experiment were within ranges used in previous studies and results were within ranges reported. The increase in yield at higher N rates could be attributed to effect of N on growth of plants and in delaying maturity which could improve assimilate partitioning to bulbs (Hegde, 1988). The higher number of lateral shoots with N fertilization likely contributed to higher bulb yield due to increased photosynthesis activity. Similar results were reported on shallot under different environmental conditions by Kebede et al. (2002) who determined effects of N, P, and K fertilizers and that any factor affecting numbers and size of bulblets affected bulb yield. The increment in marketable and total shallot bulb yield in response to increased N fertilizer is due to a corresponding increment in the number of bulb diameter ($r = 0.71^{**}$ and $r = 0.71^{**}$) and bulb weight ($r = 0.82^{**}$ and 0.83^{**}).

All improved cultivars had higher marketable and total bulb yields than the local landrace (Figure 2). Bulb yield differences between cultivars could be attributed to genetic differences governing plant development which indirectly determine bulb size through amount of carbohydrate synthesized and made available for storage in bulbs. Differences could also be due to genetic variation in root physiology and development and ability to mobilize and utilize nutrients.

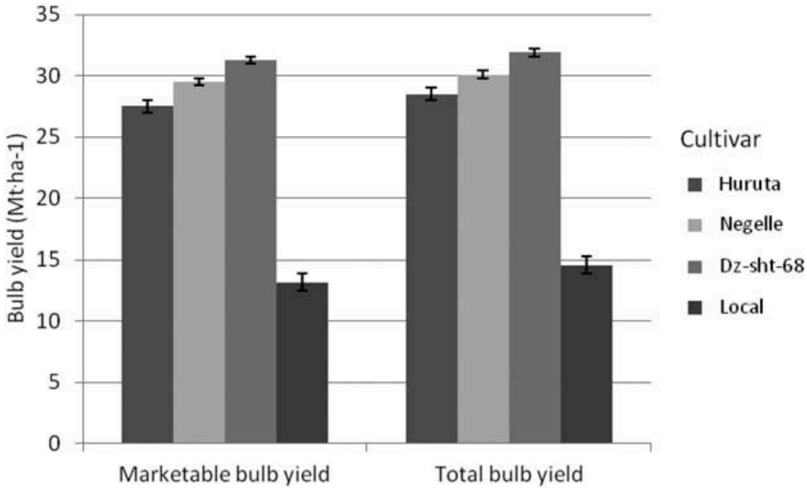

Figure 2: Marketable and total bulb yields of shallot due to cultivar in 2008.

Number of Bulb Splits and Bulb Diameter

Number of bulb splits per plant was affected by the N fertilizer and cultivar interaction (Table 1). Application of N fertilizer increased number of bulb splits in all cultivars except 'Negelle' (Figure 3). In 'Huruta' application of 50 kg·ha^{-1} N increased numbers of bulb splits over the control, while successive N levels did not produce increases. In 'Dz-sht-68' numbers of bulb splits increased with application of N above 50 kg·ha^{-1}. The highest number of bulb splits was for the local landrace at application of 100 kg·ha^{-1} N (Figure 3). Increased lateral branching, resulting in production of more bulb splits due to N fertilizer, agrees with Kebede et al. (2002) who studied effects of N, P and K fertilizers on the

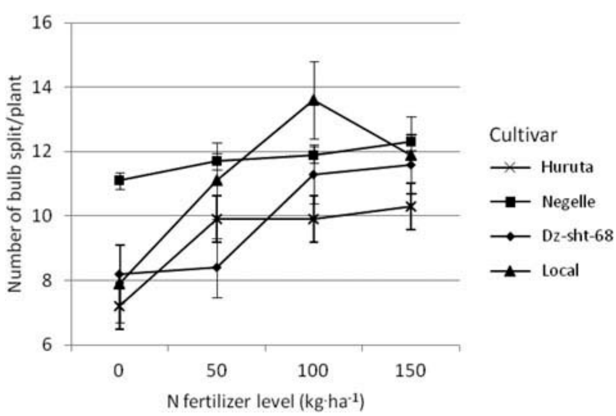

Figure 3: Interaction effect of N fertilizer and cultivar on number of bulb split per plant of shallot in 2008.

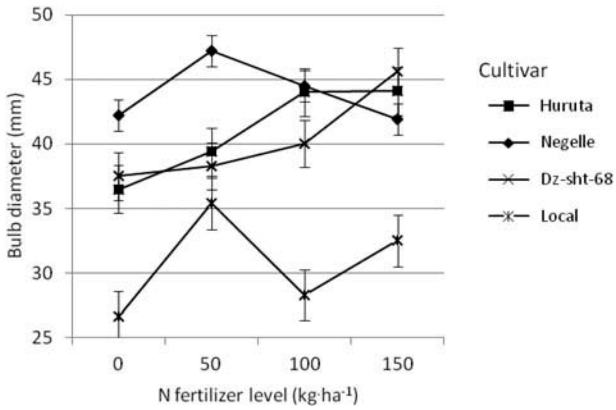

Figure 4: Interaction of N fertilizer and cultivar on bulb diameter of shallot, 2008.

shallot varieties 'Dz-Sht-78,' 'Dz-Sht-91,' and 'Fedis' in a sub-humid climate with a heavy clay (about 50%) soil. This may indicate that these results are suitable over a range of environmental conditions.

Bulb diameter was affected by the interaction of N fertilizer and cultivar (Table 1). 'Negelle' surpassed the other cultivars at 0 and 50 kg·ha^{-1} N levels (Figure 4). The lowest bulb diameter was for the local landrace at all N levels, except at 50 kg·ha^{-1} N. In 'Huruta' and 'Dz-sht-68,' bulb diameter increased with increased N fertilizer. In the local landrace, widest bulbs were with 50 kg·ha^{-1} N, which was still less than the bulb diameter of the other varieties with no N application (Figure 4).

Bulb Dry Matter, Total Soluble Solid (TSS) Content, and Bulb Pungency

Bulb dry matter content was affected by cultivar, but not by nitrogen fertilizer or the interaction (Table 1). TSS content was affected by nitrogen fertilizer and cultivar, but not by the interaction (Table 1). Lack of response to N fertilization in dry matter content agrees with Hussien (1996) and Kebede et al. (2002). The lack of response could be attributed to high gibberellic acid activity which leads to higher carbohydrate allocation to shoots (Brewster, 1994). It could also be due to production of more foliage at the expense of bulb production (Kebede, 2003b). Conversely, Tekalign et al. (2012) reported a decrease in dry matter content with nitrogen fertilization which was attributed to the low gibberellic acid (GA) biosynthesis. Gibberellic acid regulates the pattern of assimilate partitioning and low GA level resultes in more dry matter allocation to roots. The local landrace had the highest bulb dry matter content (Figure 5). All improved cultivars had comparable bulb dry matter content.

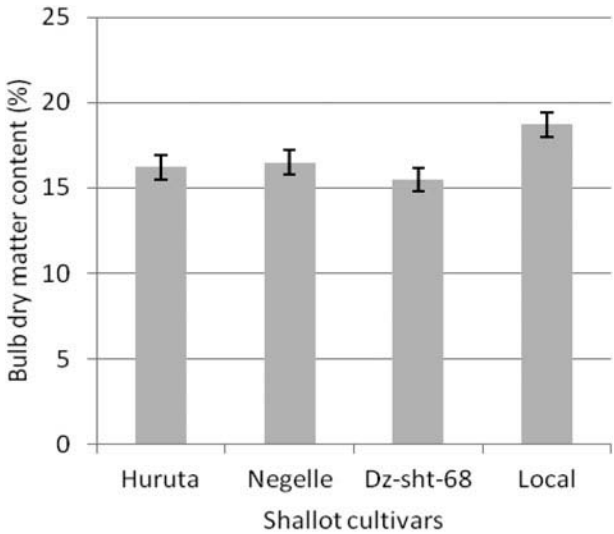

Figure 5: Effect of cultivar on bulb dry matter Content, 2008.

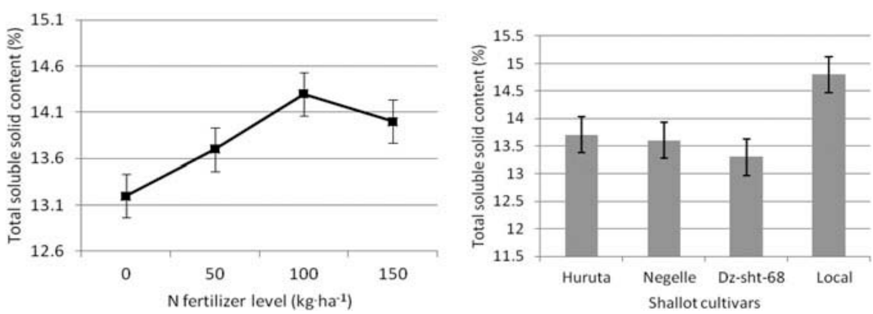

Figure 6: Effect of nitrogen fertilizer (*left*) and cultivar (*right*) on shallot total soluble solid content, 2008.

Nitrogen fertilizer affected TSS content (Figure 6). The TSS content increased up to application of 100 kg·ha^{-1} N and decreased above that. All cultivars had comparable TSS content, except the local landrace, which had the highest TSS content (Figure 6). The higher TSS in the local landrace could be associated with presence of small-sized bulbs. Mallor et al. (2010) indicated cultivars with high bulb yields have lower TSS content compared with cultivars with lowest yields, which could be due to production of few, small-sized bulbs.

In the current study bulb pungency (pyruvate content) was not affected by treatment. This disagrees with Kebede (2003b), Sebsbe and Workneh (2010), and Tekalign et al. (2012) who reported increased pyruvate content due to application of nitrogen fertilizer. According to Randle (2000) increased pyruvate content with nitrogen fertilization could partly be explained by greater synthesis and accumulation of sulphur-containing amino acids that are precursors of flavor compounds and pyruvate.

Bulb Weight Loss

Cultivar and nitorgen fertilization did not affect cumulative weight loss of shallot until the 3rd biweekly storage assessment period; during the fourth and fifth biweekly storage assessment periods weight loss occurred due to nitrogen fertilizer rate and cultivar (Table 2). As storage period increased, there was an increase in cumulative weight loss which could be due to dry matter and water loss from bulbs. At the fourth and fifth biweekly storage assessment periods bulb weight loss was higher with application of 100 and 150 kg·ha^{-1} N (Figure 7), with losses as high as 13.6 to 17.1%. The highest bulb weight loss at higher N fertilizer levels could be due to development of larger bulbs that have higher rates of respiration. Jilani et al. (2004) reported that large size bulbs of bulb onion stored for 120 days at ambient condition lost more weight compared with small and medium size bulbs. Tekalign et al. (2012) also reported high

Table 2: Analysis of variance for effects of nitrogen fertilizer and cultivar on cumulative weight loss (%) of marketable bulbs of shallot at periods in storage (mean square values).

Source of variation	df	1st biwk storage	2nd biwk storage	3rd biwk storage	4th biwk storage	5th biwk storage	6th biwk storage
Nitrogen (N)	3	2.21	9.49	42.03	151.43*	197.24*	385.25***
Cultivar (C)	3	0.27	0.20	84.43	246.04**	502.97***	616.48***
N × C	9	8.02	16.61	26.09	41.71	60.10	171.44**
Error	30	3.47	20.93	34.58	39.90	47.80	52.95

*Significant at $p \leq 0.05$, **significant at $p \leq 0.01$, ***significant at $p \leq 0.001$ ANOVA = analysis of variance. biwk = biweekly.

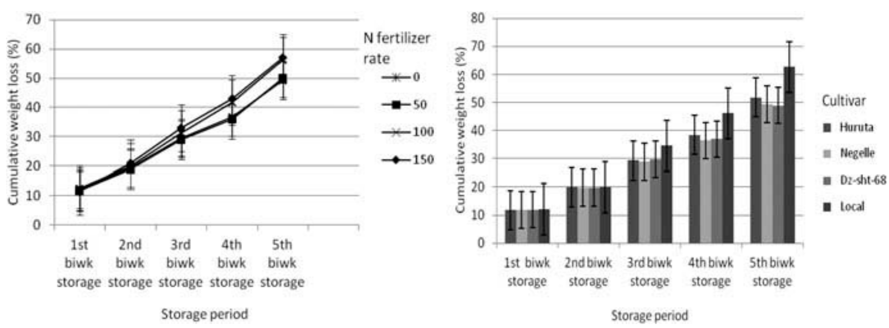

Figure 7: Effect of nitrogen fertilizer (*left*) and cultivar (*right*) on shallot cumulative weight loss (%) of marketable bulbs, 2008.

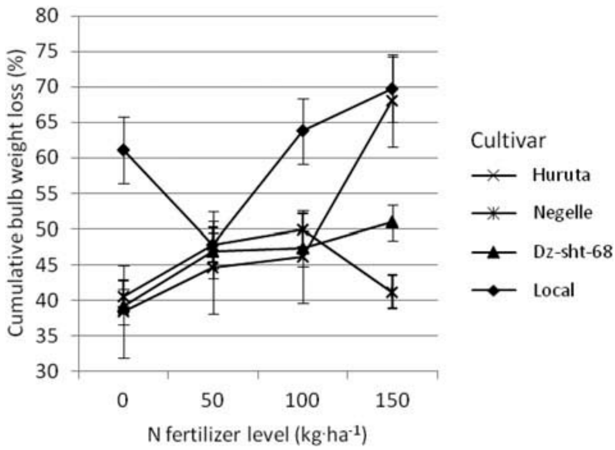

Figure 8: Interaction effect of N fertilizer level and cultivar on cumulative bulb weight loss (%) after 3 mo storage.

onion bulb weight losses as N application rate increased. Our results indicate that storage after 15 days resulted in an unacceptable level of bulb weight loss.

Among cultivars, the highest bulb weight loss was for the local landrace (Figure 7). This could be due to the thin outer skin, which cracks and peels exposing underlying tissue to moisture loss.

After 3-month storage, bulb weight loss was affected by the nitrogen fertilizer and cultivar interaction (Table 2). Weight loss in 'Huruta' was not affected by nitrogen fertilizer up to 100 kg·ha^{-1}, but was higher at 150 kg·ha^{-1} (Figure 8). Weight loss in 'Negelle' was not different due to N fertilizer level (Figure 8). In 'Dz-sht-68' weight loss was similar up to 100 kg ha^{-1} N, but slightly increased at 150 kg·ha^{-1} N. The local landrace had the highest weight loss (Figure 8). Application of N at 150 kg·ha^{-1} increased bulb weight loss in 'Huruta' and the local landrace by about 67%, compared with 'Negelle' which had the least bulb weight loss (Figure 8).

Bulb Rotting

Bulb rotting was affected by nitrogen fertilizer and cultivar, but not the interaction. Nitrogen fertilization affected bulb rotting at the first, third, and fourth biweekly storage assessment periods (Figure 9), where the highest percent bulb rotting was due to application of 100 and 150 kg·ha^{-1} N. The increase in rotted bulbs could be attributed to production of bulbs with soft and succulent tissues which made them susceptible to attack of disease causing microorganisms (Tekalign et al., 2012) and to production of onion bulbs with thick necks, which are difficult to dry. The result agrees with Sebsebe

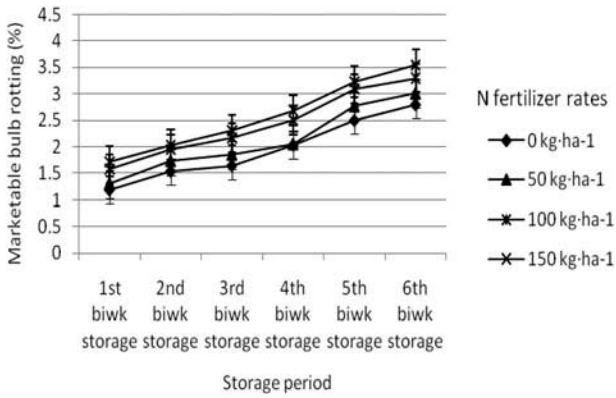

Figure 9: Effect of N fertilizer on marketable bulb rotting (%) of shallot at periods in storage. Data values are square root transformed.

Table 3: Effect of cultivar on marketable bulb rotting (%) of shallot at periods in storage.

Cultivar	1st biwk[a] storage	2nd biwk storage	3rd biwk storage	4th biwk storage	5th biwk storage	6th biwk storage
'Huruta'	1.5 (1.27)b	2.5 (1.62)	3.0 (1.72)b	4.1 (2.01)b	5.8 (2.38)b	7.3 (2.71)b
'Negelle'	1.9 (1.50)b	2.6 (1.70)	3.2 (1.85)b	4.6 (2.18)b	6.2 (2.52)b	6.9 (2.64)b
'Dz-sht-68'	1.2 (1.25)b	2.8 (1.74)	3.7 (1.97)ab	5.1 (2.28)b	7.7 (2.76)b	9.2 (3.01)b
Local	2.8 (1.76)a	4.5 (2.18)	5.7 (2.41)a	7.5 (2.80)a	15.5 (3.93)a	18.7 (4.31)a
Significance	*	NS	*	*	***	***
SED	0.18	0.20	0.23	0.24	0.29	0.31
CV (%)	30.9	26.9	28.9	25.1	24.3	24.0

NS = non-significant, *significant at $p < 0.05$, ***significant at $p < 0.001$. Data in brackets are square root transformed values.
[a]biwk = biweekly.
Values in columns followed by the same letter(s) are not significantly different, $p < 0.05$, by analysis of variance (ANOVA).

and Workneh (2010) and Tekalign et al. (2012) where increased rotting of bulb onion bulbs was due to increased N fertilizer rate.

Cultivars differed in bulb rotting during most of the storage period (Table 3), where the highest bulb rotting was for the local landrace. All improved cultivars had similar, lower, bulb rotting. The highest rotting loss in the local landrace could be due to the thin outer scale of bulbs, common to yellow skin cultivars, which favor infection and development of microorganisms.

Bulb Sprouting and Rooting

Significant differences in bulb sprouting and rooting were not observed between N fertilization levels, cultivars and their interactions. Sprouting of bulbs was not observed throughout the storage period. Absence of bulb sprouting could be attributed to curing before storage, high temperature, and low relative humidity in storage that enhances drying of bulbs, hindering sprouting. These findings were similar to Hussien (1996) who found that N fertilizer application did not affect sprouting in shallot. In contrast, Sebsebe and Workneh (2010) observed that sprouting in shallot increased with increasing nitrogen from 0 to 150 kg·ha^{-1} N. Tekalign et al. (2012) reported increased sprouting of bulb onion bulbs during 8 weeks of storage due to N and P fertilization. Dankhar and Singh (1991) reported that high N produced thick-necked bulbs that increased sprouting in storage due to greater access of oxygen and moisture at the central growing point. Differences in results may be due to plant material used, location, growing or storage conditions.

Shallot growers could maximize bulb yield by applying nitrogen fertilizer at 100 kg·ha^{-1} and using the high-yielding cv. 'Dz-sht-68.' Increasing nitrogen rate could increase yield and yield components, but could compromise bulb shelf-life as it increases bulb weight loss and bulb rotting. Growers should apply N fertilizer at 100 kg·ha^{-1} if bulbs are to be stored for short periods.

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